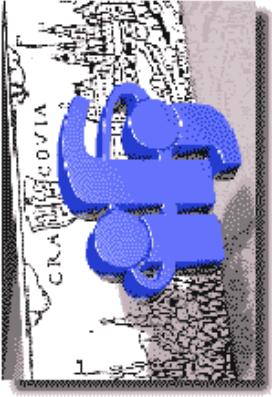




# B-Physics at TEVATRON



## Representing the CDF and D $\emptyset$ Collaborations



1 May 2002

DIS 2002 Conference, Kraków, Poland

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*Tufts University, Boston, USA*

*Institute of Nuclear Physics, Kraków, Poland*

1 May 2002

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# Why B – Physics?

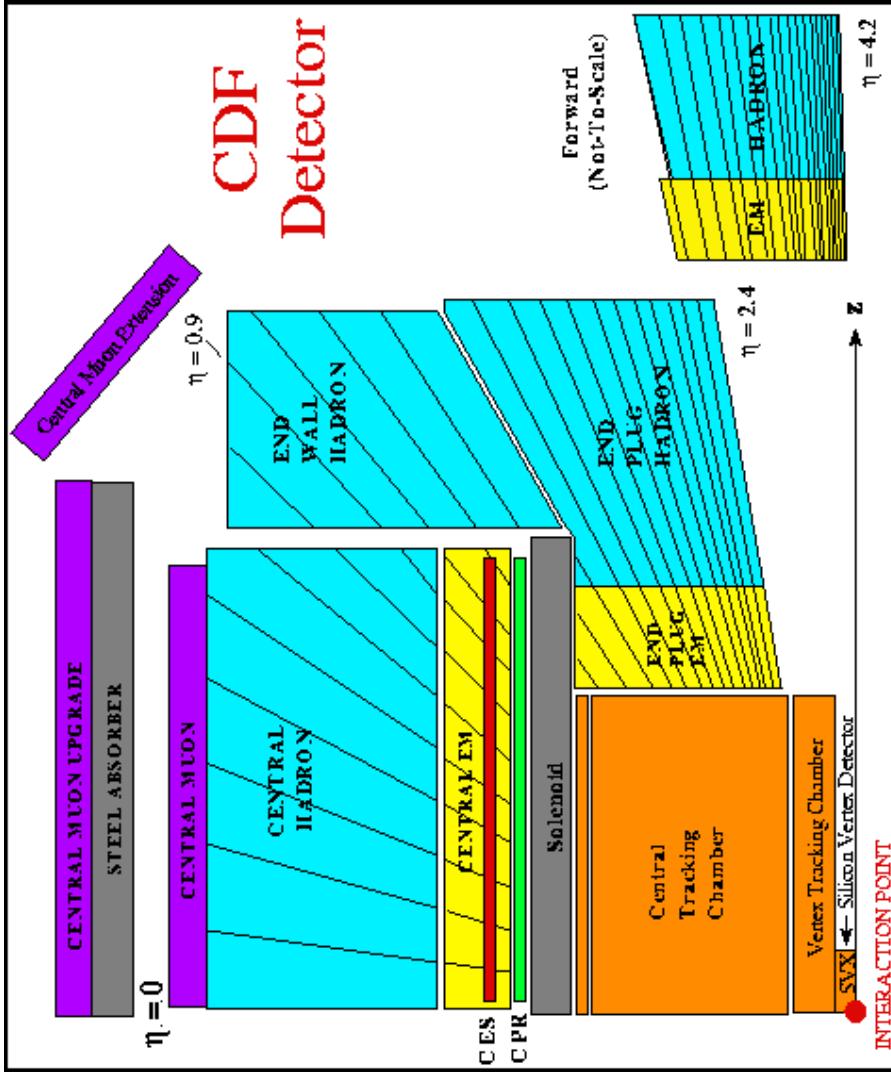
## CDF and D $\emptyset$ experiments

- High cross-section for  $b\bar{b}$  production in  $p\bar{p}$  collisions  $\approx 100 \mu b$  – Tevatron is a B-factory!
- CP violation studies – tests of Standard Model.
- Spectroscopy of B mesons.



# B-Physics at CDF Run I

- Years 1992-1996.
- 110 pb<sup>-1</sup> at 1.8 TeV energy.



Good vertex detector  
is essential.



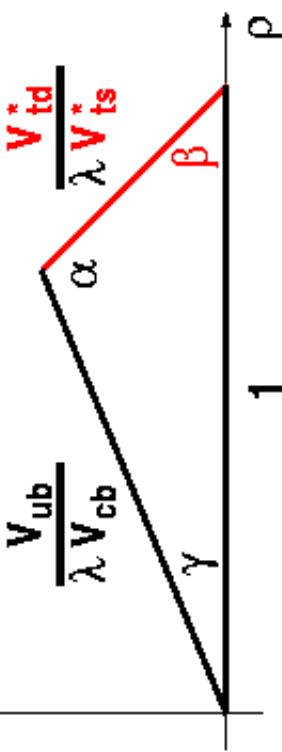
# CP violation in B-meson system

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$V_{tb}^* V_{td} + V_{cb}^* V_{cd} + V_{ub}^* V_{ud} = 1$$

$$\lambda = \sin \theta_c$$

**weak eigenstates  $\neq$  mass eigenstates**  
**Mixing described by unitarity**  
**Cabbibo-Kobayashi-Maskawa matrix.**



$$V = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

**Unitarity triangle.**  
*Is the triangle unitary?*  
**Search for a new physics...**

**Wolfenstein Parametrization of the CKM matrix -  $\eta \neq 0$  means CP violation.**

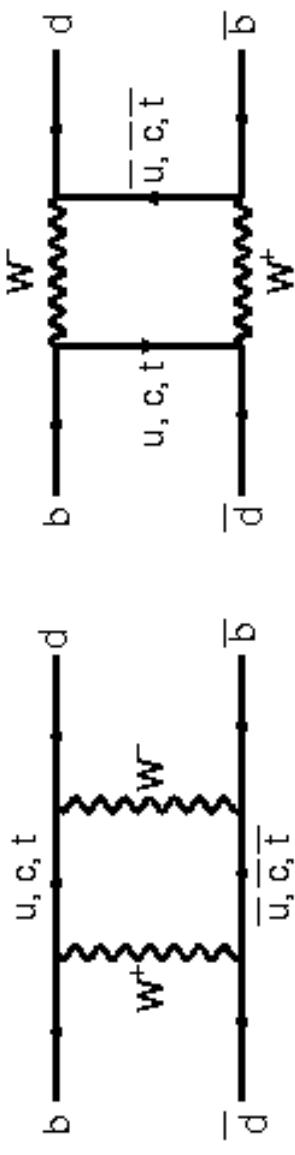
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# CP violation in $B_d$ system

Mixing depends on CKM matrix



*t*-quark dominates:

$$\Delta m_d \propto |V_{tb}^* V_{td}|^2$$

$J/\psi K_s^0$  is a CP eigenstate, therefore:

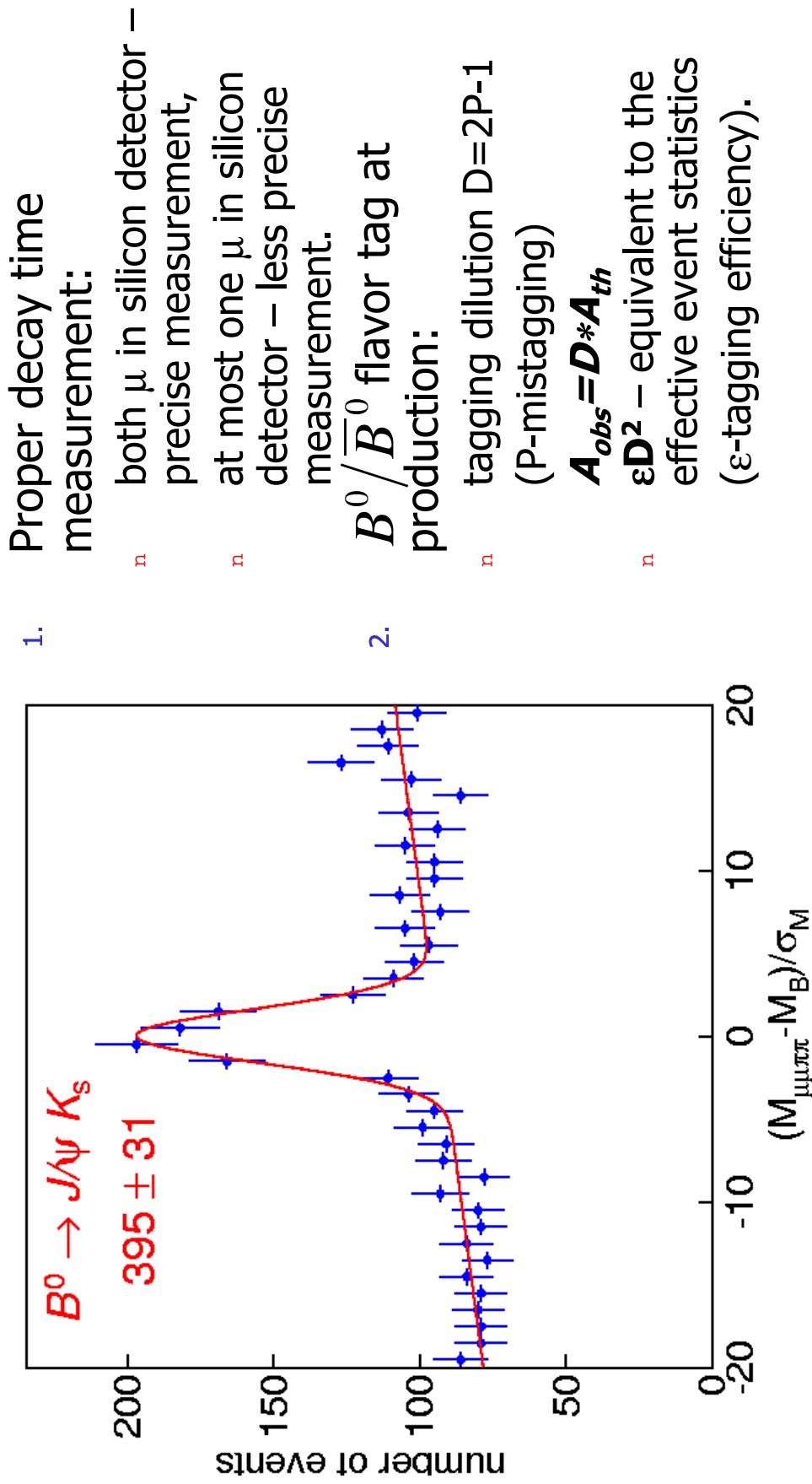
$$\Gamma(B_{t=0}^0 \rightarrow J/\psi K_s^0) \neq \Gamma(\bar{B}_{t=0}^0 \rightarrow J/\psi K_s^0)$$

$$A(t) = \frac{N(t) - \bar{N}(t)}{N(t) + \bar{N}(t)} \propto \sin(2\beta) \cdot \sin(\Delta m_d t)$$

Integrated asymmetry  $A_{CP} \propto \sin 2\beta$  is also a measure of CP violation.

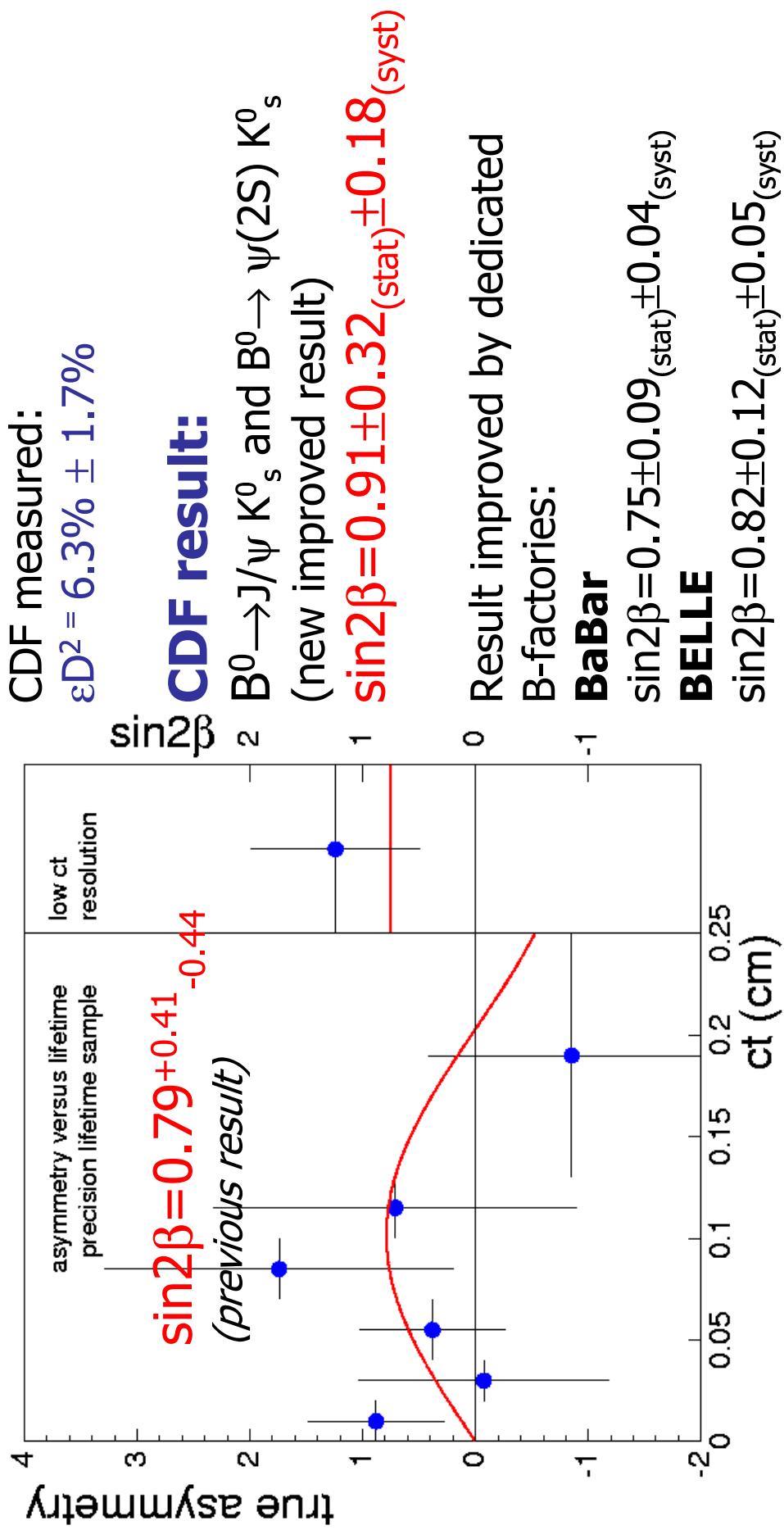


# Experimental aspects





# CDF $\sin 2\beta$ measurement

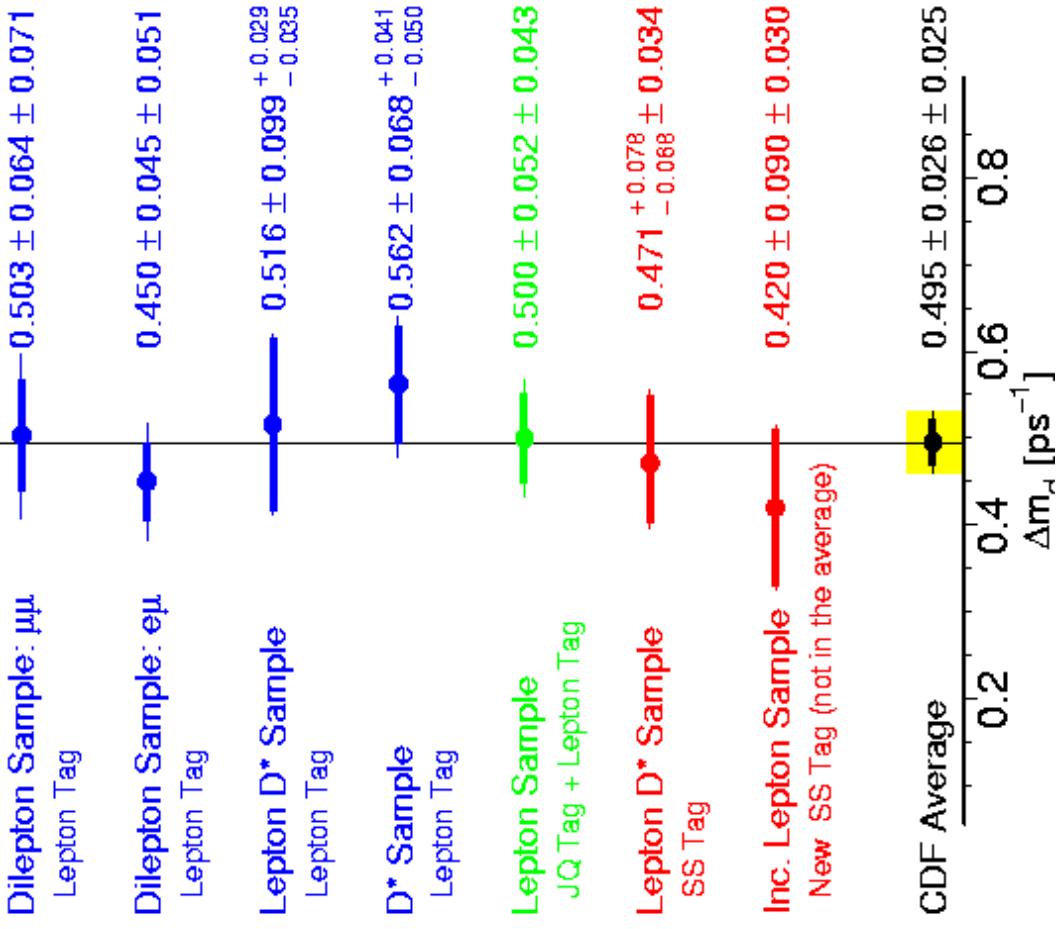


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# B<sup>0</sup> mixing measurement



Various taggers: soft lepton,  
same side  $\pi$ , opposite side  
jet charge.

$$\Delta m_d = \mathbf{0.495 \pm 0.026_{(stat)} \pm 0.025_{(syst)}}$$

Present B Factories  $\Delta m_d$  errors:  
 $\pm 0.010$  ps<sup>-1</sup> Babar  
 $\pm 0.008$  ps<sup>-1</sup> Belle

## CDF limit on B<sup>0</sup><sub>s</sub> mixing:

$\Delta m_s > 5.8$  ps<sup>-1</sup> at 95% CL  
Since  $|V_{ts}| > |V_{td}|$  then  $\Delta m_s >> \Delta m_d$   
- fast oscillations for B<sup>0</sup><sub>s</sub> decays.

$$\Delta m_s \propto \left| V_{tb}^* V_{ts} \right|^2$$



# Other Run I CDF highlights

n Masses and lifetimes of heavy  
B hadrons (not produced at  
 $e^+e^-$  machines):

$$m(B_S) = 5.3699 \pm 0.0023 \pm 0.0013 \text{ GeV}$$

$$m(\Lambda_B) = 5.621 \pm 0.004 \pm 0.003 \text{ GeV}$$

$$\mathbf{m(B_c) = 6.40 \pm 0.39 \pm 0.13 \text{ GeV}}$$

$$\tau(B_S) = 1.36 \pm 0.10 \text{ ps}$$

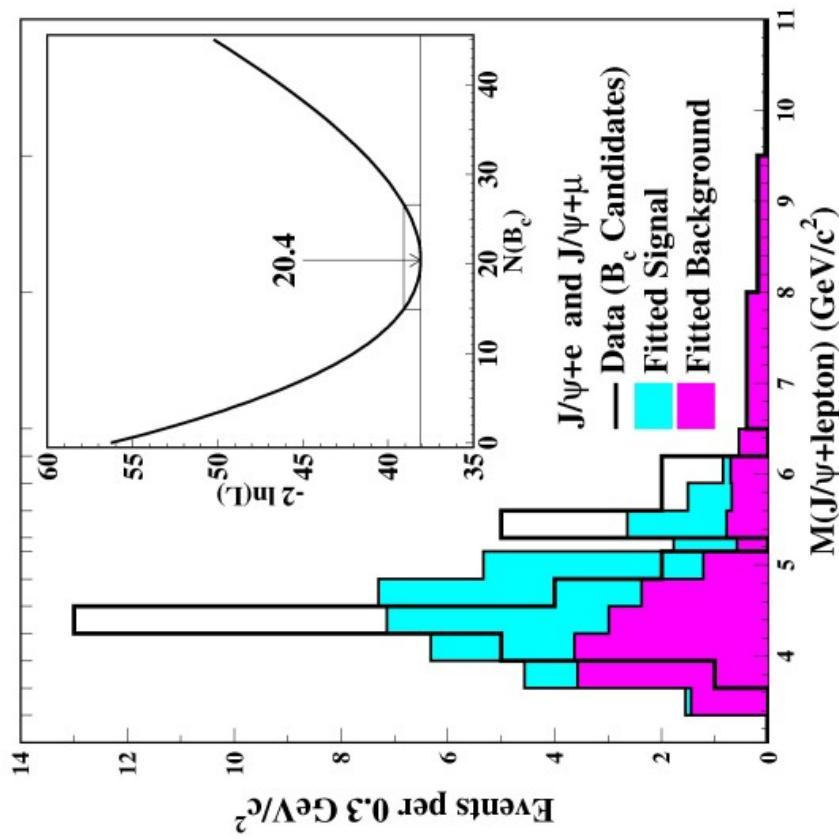
$$\tau(\Lambda_B) = 1.32 \pm 0.17 \text{ ps}$$

$$\mathbf{\tau(B_c) = 0.46 \pm 0.17 \text{ ps}}$$

(the only measurement)

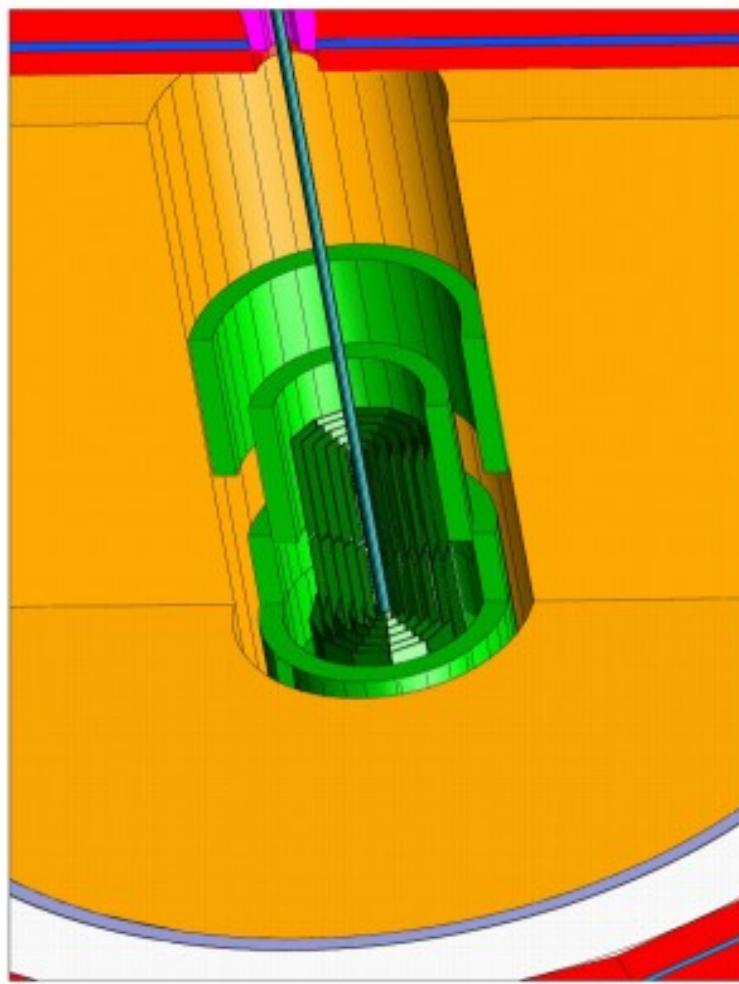
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## Run II CDF upgrades



- $L=2 \text{ fb}^{-1}$  (Run IIa)  
at 1.96 TeV (high luminosity)
- New CDF silicon tracker (r-z  
and r- $\phi$  measurement,  
accuracy increased by 1.4)
- New Tracking Chamber COT
- New DAQ – less dead time
- TOF system -  $\varepsilon D^2$  increased  
by two to about 11%
- Trigger on displaced vertices

## CDFtracking



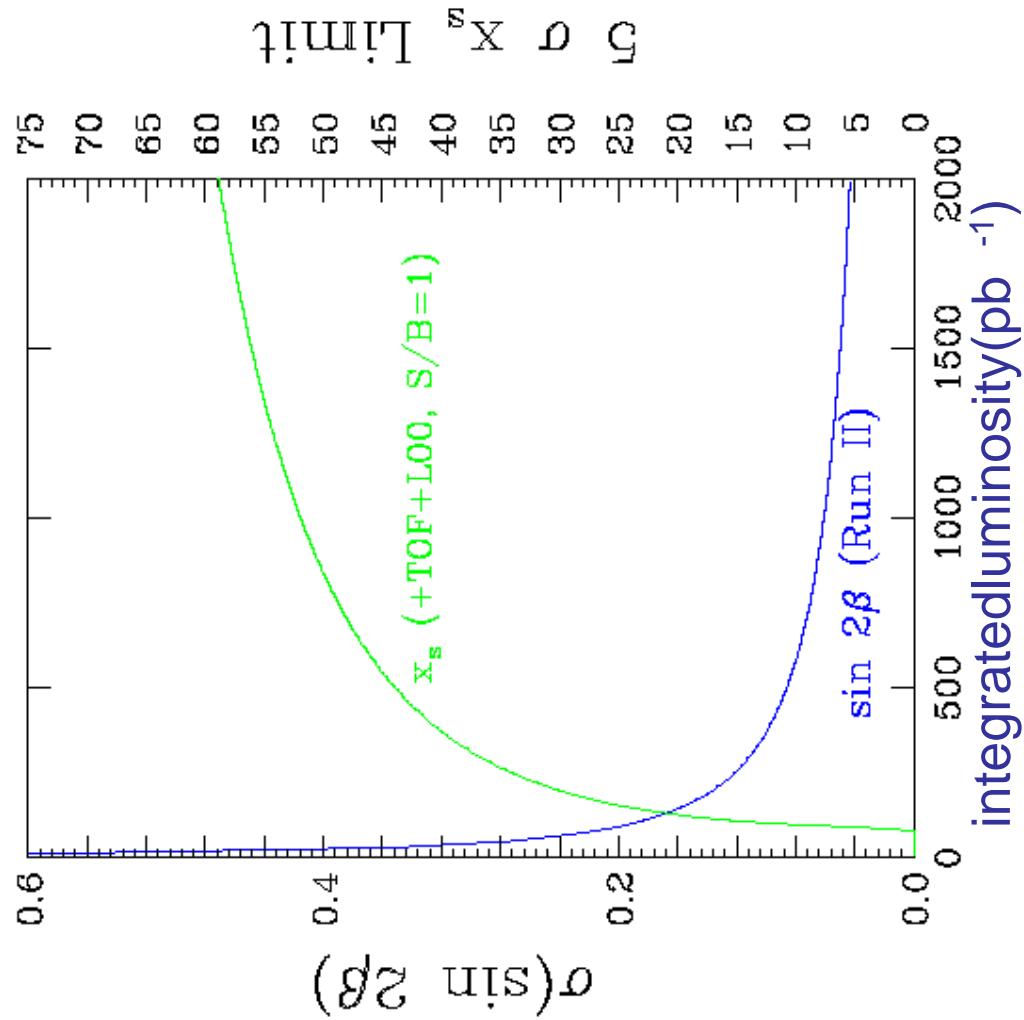
# Run II CDF B-physics prospects

Improved measurement of  
 $\sin(2\beta)$  in  $B^0 \rightarrow J/\psi K^0_S$ :  
 $\approx 20000$  events

$$\sigma(\sin 2\beta) \approx 0.05$$

$B_S$  mixing in  $B_S \rightarrow D_S \pi^+$   
sensitivity up to about  
 $X_S \approx 60$  ( $\approx 23000$  events)  
 $X_S \approx 30$  in semileptonic decays

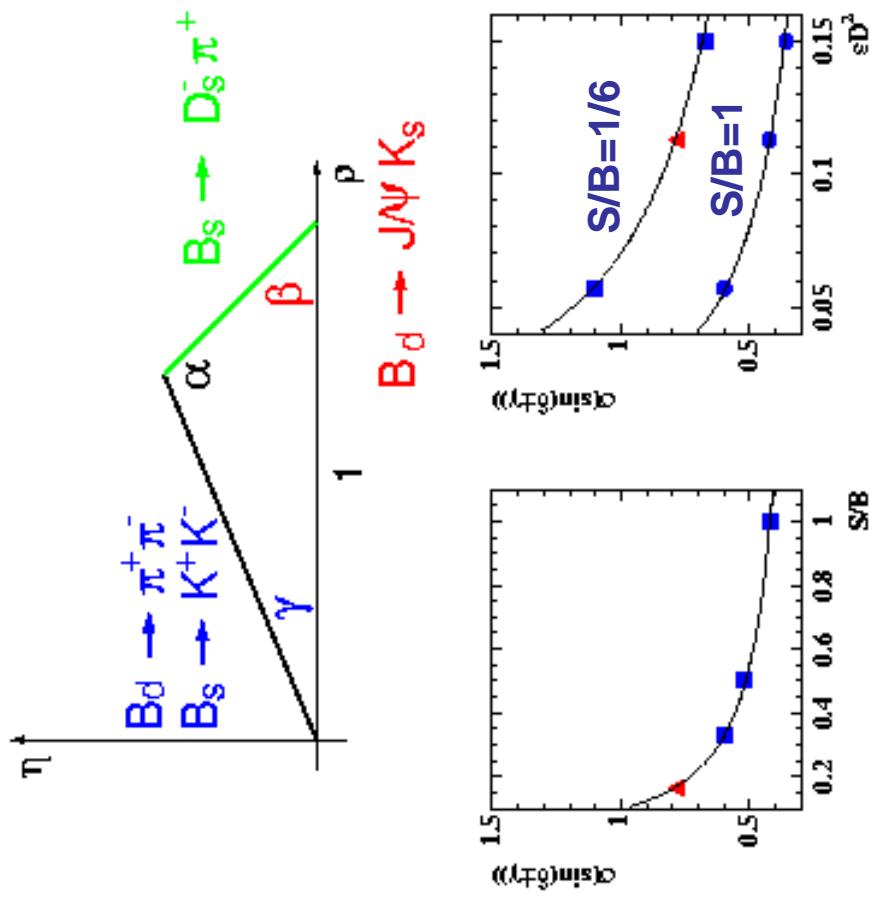
$$X_S = \Delta m_S / \Gamma_S$$





# Run II CDF $\gamma$ measurement

- Measurement of  $\gamma$  in  $B_d^0 \rightarrow \pi^+\pi^-$  and  $B_s^0 \rightarrow K^+K^-$  decays.
- Use of both decays reduces the influence of penguins.
- Assuming  $S/B=1/2$  and  $\Delta m_S = 30 \text{ ps}^{-1}$ ; events:  
 $5000(\pi^+\pi^-)/10000(K^+K^-)$ :  
 $\sigma(\gamma) \approx 7^0$





# CDF $\Delta\Gamma_S/\Gamma_S$ analysis

Measuring lifetime difference between  $B_S^H$  (short, heavy) and  $B_S^L$  (long, light).

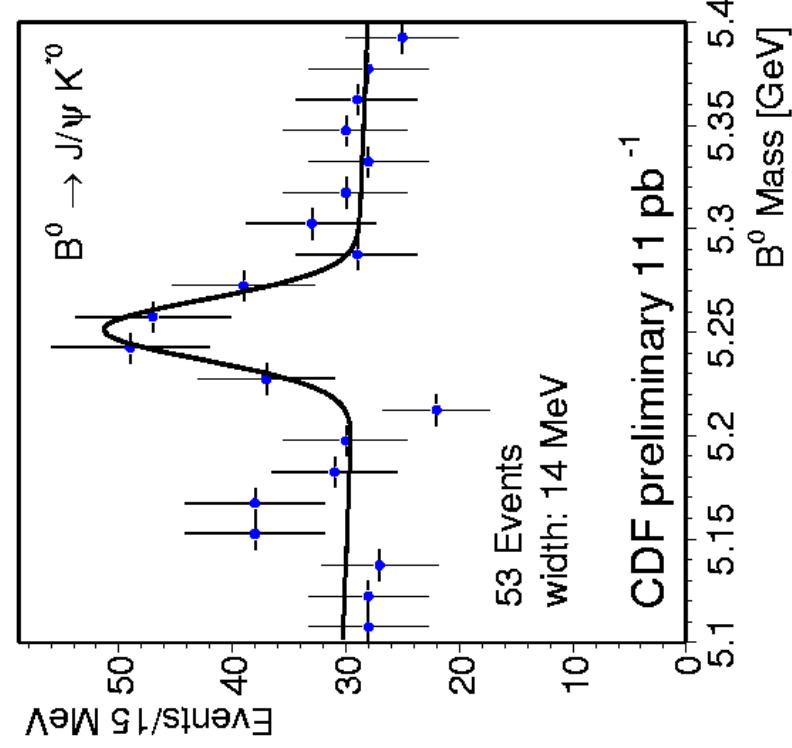
- $B_S \rightarrow J/\psi \phi$  decays (4000 events), angular analysis used to separate  $B_S^H$  and  $B_S^L$ .
- $B_S \rightarrow D_S^+ D_S^-$  - pure CP even eigenstate.
- Expected error  $\sigma(\Delta\Gamma_S/\Gamma_S) = \mathbf{0.06}$

Assuming 77% of CP even fraction (RunI result):  
 $\sigma(\Delta\Gamma_S/\Gamma_S) = \mathbf{0.05}$

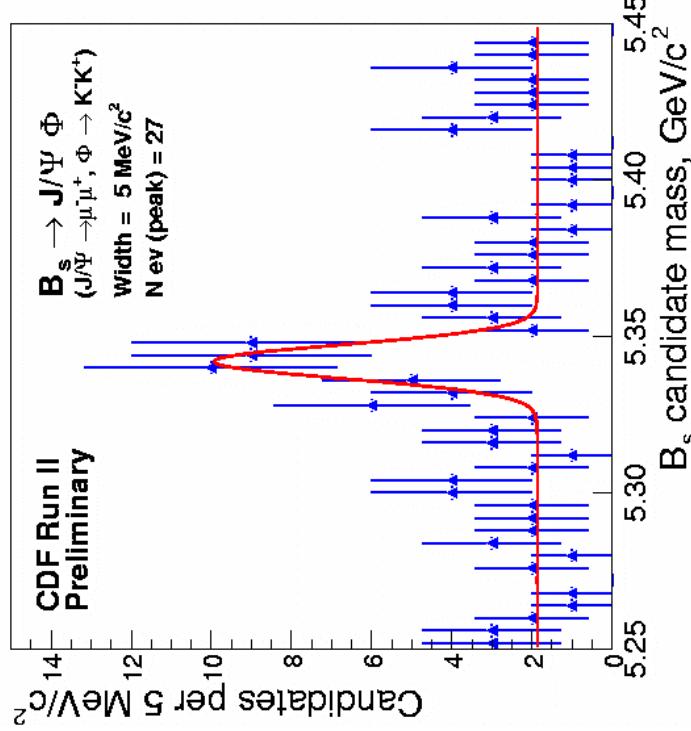
Combined:  $\sigma(\Delta\Gamma_S/\Gamma_S) = \mathbf{0.04}$



# First CDF data from Run II



Observation of  $B^0 \rightarrow J/\psi K^{*0}$   
and  $B_s \rightarrow J/\psi \phi$  decays.

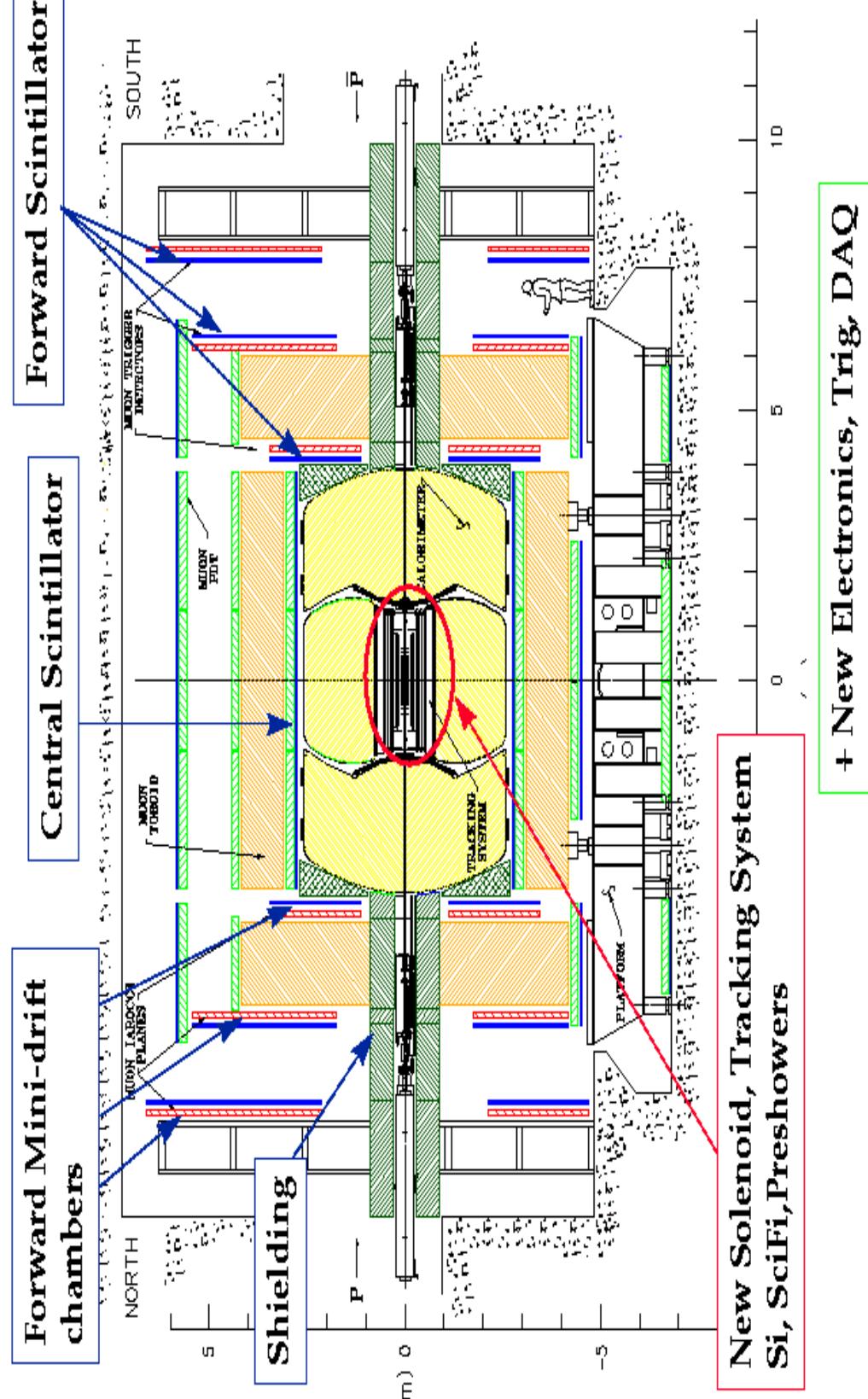




# Summary of CDF Run III prospects

- Improved  $\sin 2\beta$  measurement  
 $\sigma(\sin 2\beta) \approx 0.05$ .
- Measurement of angle  $\gamma$  with  $\sigma(\gamma) \approx 7^0$ .
- Observation of  $B_S$  mixing.
- $\Delta\Gamma_S$  measurement.
- Improved measurements of  $B$  mesons lifetimes and masses.
- Search for rare decays.

# Run II DØ upgrades



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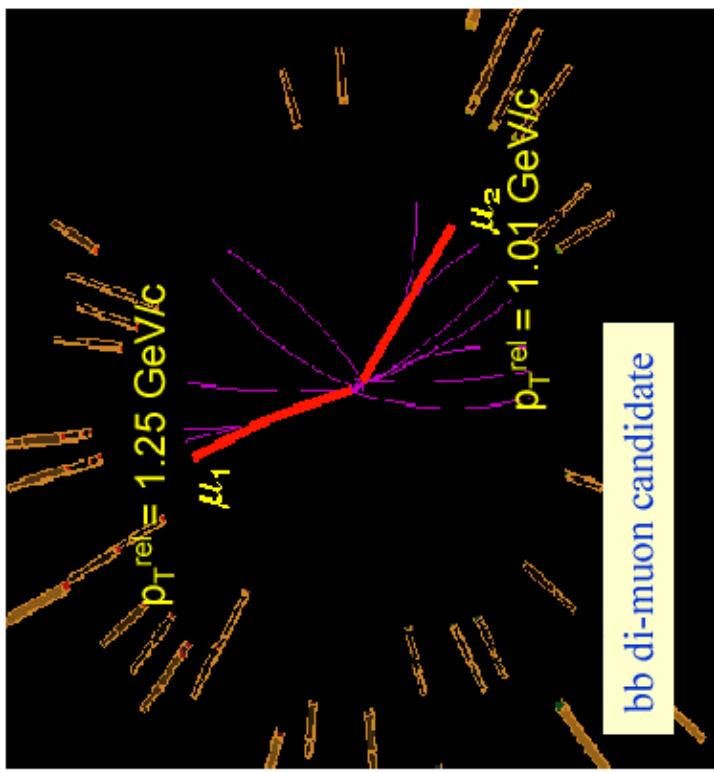
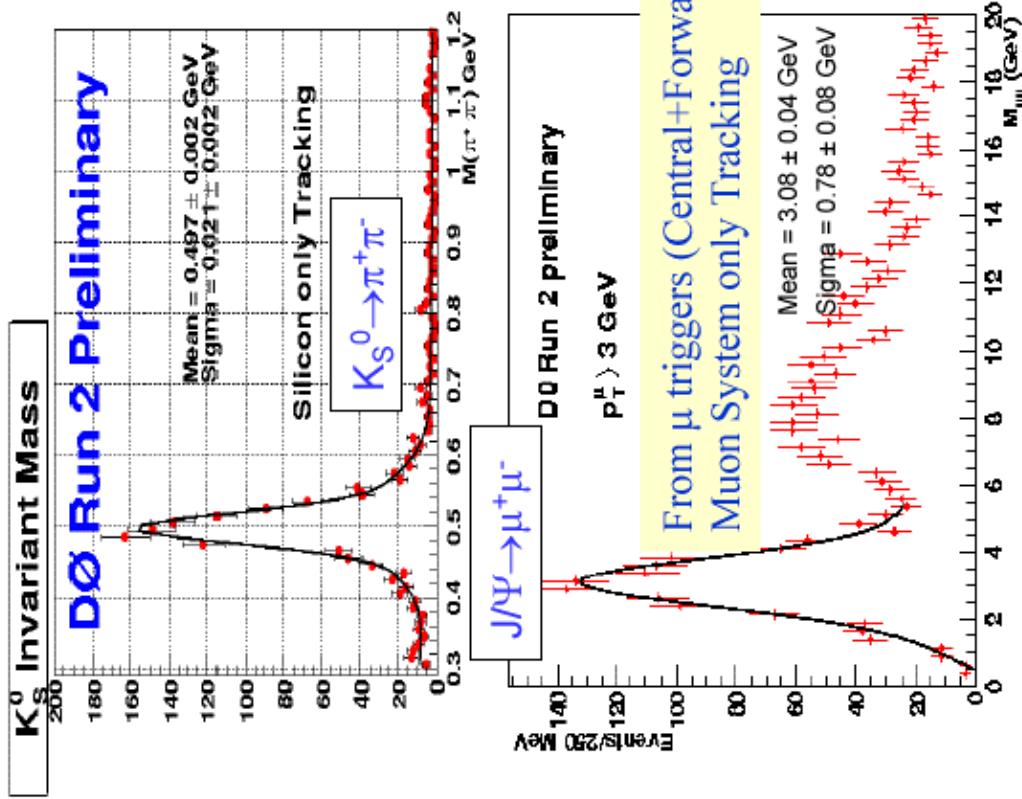
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## Run II DØ upgrades

- n **STT (Silicon Track Trigger)** is coming online late summer. The Silicon Microstrip Tracker information is used to allow triggering on tracks with impact parameter resolution of  $\sim 30 \mu\text{m}$  (including the beam spot width) at Level 2.
- n **Excellent lepton coverage:**
  - muons:  $p_T > 1.5 \text{ GeV}, |\eta| < 2$
  - electrons:  $p_T > 1 \text{ GeV}, |\eta| < 2.5$
- n **High tracking coverage:**
  - at least 95% efficiency for  $|\eta| < 3$

# First DØ data from Run II



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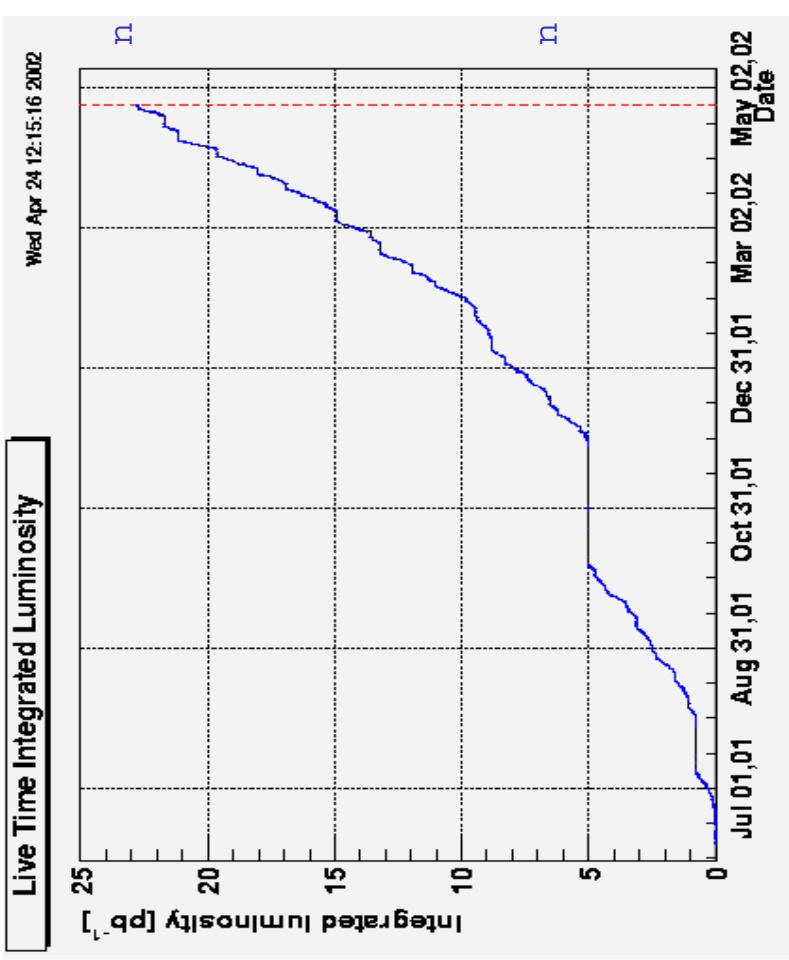
# DØ Run II physics prospects

## DØ in 2 years (2 fb<sup>-1</sup>) will have:

- measurement of  $\sin 2\beta$  to an accuracy of 0.04 (40 000 events, more than CDF due to better coverage, but worse lifetime resolution).
- measurement of (or a limit on)  $B_s$  mixing up to  $X_s \approx 30$  (semileptonic B decays, similar to CDF limit for this channel).
- limits on other CKM angles  $\alpha, \gamma$
- measurement of  $\Lambda_b$  lifetime in exclusive decays.
- rare decays, heavy baryons, .....



# Run II status



Tevatron is planning to deliver  
70 pb<sup>-1</sup> until September  
(2000 pb<sup>-1</sup> until end of 2002),  
but up to now < 25 pb<sup>-1</sup>  
delivered.

Both CDF and DØ experiments  
waiting for Tevatron.



# Summary

## Run I – rich physics results

- first observation of  $B_c$
  - measurement of  $\sin 2\beta$
  - $B$  meson masses, lifetimes
- ## Run II – promising physics prospects for CDF and DØ
- constrain unitarity triangle – measure  $\sin 2\beta$ ,  $\gamma$ ,  $B_s$  mixing
  - precise measurements of  $B$  meson masses and lifetimes.

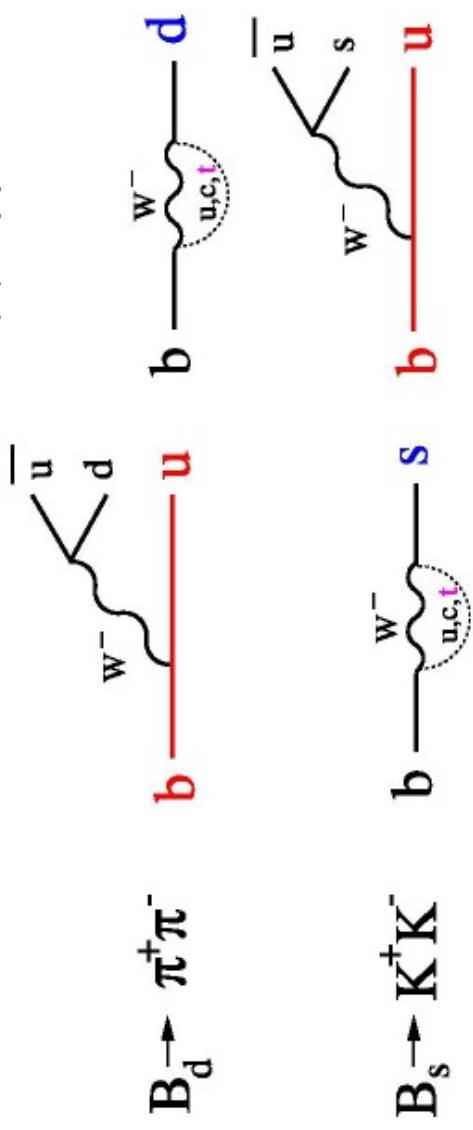
**Incredibly interesting physics to come!**



# Description of $\gamma$ measurement

Dominant

Subdominant  
 $O(\lambda)$  suppressed



Both decays are related by interchanging all  
d and s quarks. Both final states are CP  
eigenstates.

*FleischerPLB459(1999)306*

systematics: 20%  $SU(3)$  breaking

$$\sigma(\gamma) \left[ {}^{+5.4^{\circ}}_{-6.8^{\circ}} \text{ (stat)} \right] > 3^{\circ} \text{ (sys)}$$

$$\sigma(A_{cp}(B_s^- K^- K_+)) \left[ 0.08, \sigma(A_{cp}(B_0^- \pi^- \pi_+)) \right] 0.14$$

## Results

Assume:  $S/B = 1/2$ ;  $\Delta m_s = 30 \text{ ps}^{-1}$ 

$$A_{mix}(J/\psi K_s) = \sin 2\theta$$

$$A_{mix}(\pi^+ \pi^-) = \frac{\sin 2(\beta + \gamma) - 2d \cos \theta \sin(2\beta + \gamma) + d^2}{1 - 2d \cos \theta \cos \gamma + d^2} \sin 2\beta$$

$$A_{mix}(K^+ K_-) = \frac{1 + 2d \frac{1 - 2\beta}{2} \cos \theta \cos \gamma + d^2 \frac{1 - 2\beta}{2}^2}{\sin 2\gamma + 2d \frac{1 - 2\beta}{2} \cos \theta \sin \gamma} \cos \theta \sin \gamma$$

$$A_{dir}(K^+ K_-) = \frac{1 + 2d \frac{1 - 2\beta}{2} \cos \theta \cos \gamma + d^2 \frac{1 - 2\beta}{2}^2}{2d \frac{1 - 2\beta}{2} \sin \theta \sin \gamma} \sin \theta \sin \gamma$$

$$A_{dir}(\pi^+ \pi^-) = \frac{1 - 2d \cos \theta \cos \gamma + d^2}{2d \sin \theta \sin \gamma} \sin \theta \sin \gamma$$

$$A_{cp}(t) = A_{dir} \cos \Delta mt + A_{mix} \sin \Delta mt$$

Five observables

 $\gamma, \beta$  = weak phases $\theta$  = phase of above  $d$  $d$  = ratio of hadronic matrix elements "P/T"

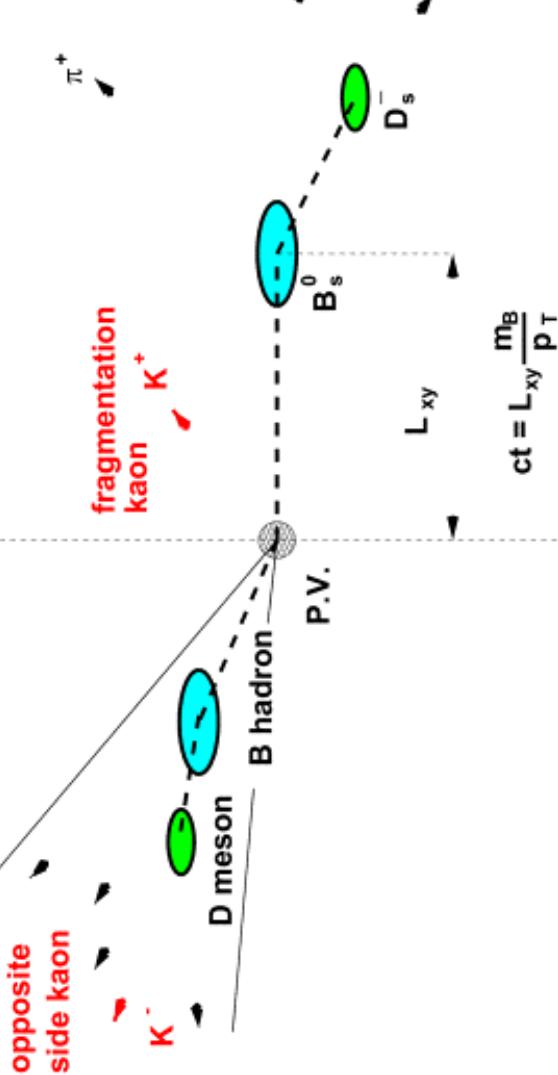
Four parameters Feischer PLB 459 (1999) 306

Measuring  $\gamma$  for Real



# Jet tagging algorithms

opposite side same side (vertexing)



n Same side tagging SST –  
tags on correlations  
between  $B^0$  and nearby  
hadrons.

n Opposite side jet-charge  
tagging (JETQ).

n Soft lepton tagging (SLT)  
uses the sign of an soft  
opposite side muon or  
electron.